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A FUZZY BI-LEVEL AND MULTI-OBJECTIVE MODEL TO CONTROL TRAFFIC FLOW INTO THE DISASTER AREA POST EARTHQUAKE

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Abstract: After a severe earthquake, the roadway systems usually will get different levels of damage, and thus the capacity of those roadways will be reduced, which will cause the traffic congestion. How to maintain traffic functions reasonably to facilitate saving more lives will be the utmost mission task after quakes. This paper aims at providing appropriate traffic control strategies in response to various situations occurred in earthquake disaster areas. The study proposes a fuzzy multi-objective programming to represent the real situations and generate corresponding traffic control strategies. The strategies are expected to guide the emergency vehicles and control other disturbing traffic flows in/out the disaster areas. The objective of the model is to allow as many non-rescue vehicles to enter the disaster areas as possible based on two conditions: do not delay the moving of rescue vehicles and do not exceed the left available roadway capacity. Since the decision process of this traffic control problem is similar to the static two people Stackelberg game (regulators and road users), it is formulated as a bi-level fuzzy multi-objective optimization model. To prove the feasibility, this paper has conducted a numerical case study using a small sample data from the earthquake-raided areas. To solve the model efficiently, the fuzzy set theory been applied to solve the model. A numerical example shows that this study can create an effective way to implement traffic regulation during earthquake disaster.

Key Words: earthquake-raided area, traffic control management, bi-level programming, combined distribution/assignment

1. INTRODUCTION

Chi-Chi Earthquake occurred in Nantou, Taiwan, September 21, 1999 has caused serious damage to the infrastructures in the disaster areas including transportation network, gas, water and electric power systems. Damages caused road closure and traffic jam, therefore vehicles are not easy to in/out the areas. It is a major concern for the on-site operators who are in charge of delivering supplies, evacuation, rescue and restoration. Since congestion caused by damaged urban road networks becomes an important issue, efficient disaster traffic management is essential (Odani et al., 1996; Nakagawa et al., 1996). Since network capacities are possible to be decreased due to severe damages on main roads and bridges post earthquakes, how to maintain the basic road functions through traffic control/management becomes an important issue.

While a disaster situation remaining, transportation is critical in minimizing the loss of life and maximizing the efficiency of rescue operations. It is necessary to balance travel demand (traffic on a link) and traffic supply (the capacity of a network) in tackling traffic congestion. (Tomita et al., 1995) This paper discusses the determination of allowable non-emergency operation traffic flows is to ensure that the rest road network capacity under deterioration will not be exceeded at any time. The purposes of this study include three folds. First, it tries to deal with the question of how to reduce damages in earthquake-raided areas. Secondly, it hopes to provide quick and effective means to restore chaos situations post earthquakes. Finally, it provides appropriate approaches to reach the goal of supporting sustainable development of the affected areas in the future.

2. TRAFFIC CONTROL PROBLEM IN EARTHQUAKE-RAIDED AREAS

In the field of transportation, previous earthquake studies only focus on engineering designs and rescue scheduling. Few studies pay attention to the subject of traffic control and management in earthquake disaster areas. Haghani et al. (1996) formulated a complex multi-model network flow problem with time constraints reflecting the situation of disaster relief, which could be solved relatively easily. This model is trying to identify the best emergency vehicles rout choice and dispatching schedule. However, the model does not the need of non-emergency traffic flow control on each link. Masuya et al. (1996) and Kurauchi et al. (1997) have proposed ways to measure the maximum trip generation and attraction volume which can be endured by the rest capacity of the network after the impact of an earthquake. Results show that appropriate traffic demand control is needed under emergent situations. However, these models doesn’t specially distinct the needs of emergency vehicles.

Masuya et al (1999) develop a decision making tool to control non-emergency vehicles to enter disaster areas. In this paper, the problem is formulated as a multi-commodity, two-model network flow problem basing on the concept of network flow theory and integer linear programming. Since, the traffic control decision process is similar to the static two person Stackelberg game problem (G.P. Papavassilopoulos, 1982), it can be transformed to become a bi-level programming problem. In the IATSS research, IIDA（1995）presents the idea of how to against major earthquakes by traffic management system. The study develops a good study platform of traffic management using the Great Hansin-Awaji Earthquake as the background. A bi-level programming model is developed in that paper, and the model can be extended to cover both the needs of victims and those who come to rescue them.

2.1 Empirical Data Description

According to the statistics reports issued by Post-921 Reconstruction Commission, Chi-Chi Earthquake occurred at a magnitude of 7.3 in 1999, left 2,400 deaths, and more than 10,000 injured. This natural disaster is not just to cause impacts on transportation systems, but also public safety. Many towns and villages in central Taiwan were hurt seriously illustrated in Figure 1.

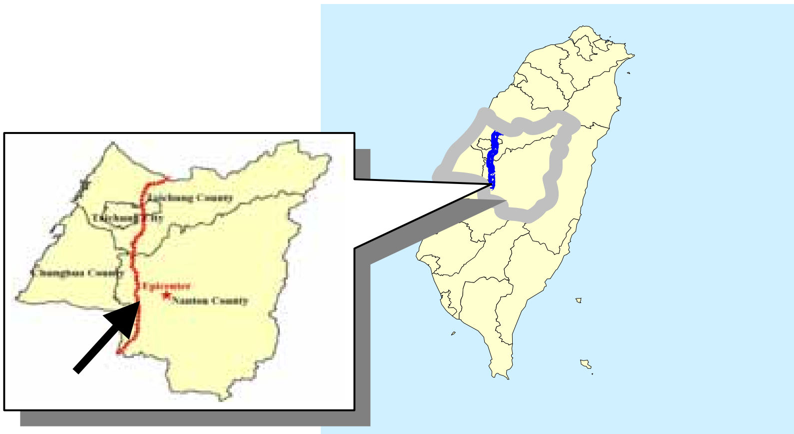

Figure1 Major Disaster Areas of Chi-Chi Earthquake

2.2 Traffic Control Problem Analysis

Experiences learned from rescue operation in Chi-Chi Earthquake tell us that although both government and private organizations have tried their best to rescue victims, but results turned out not as good as expected. There is a room to improve if it can be done again. The main difficulty is insufficient information while the earthquake occurs. Without updated information about the damages on road networks, it is difficult to perform a good traffic control to facilitate victims rescue mission. Experience implies that the following issues need to be explored.

1. Roadway damage information is inadequate in chaos situations.
2. Drivers' behaviors including OD distribution and mode choice are vague.
3. Existing command and decision-making systems are not able to direct traffic to in/out the disaster areas rationally.

4. For real time managing traffic flows to facilitate on-site rescue operation, a dynamic traffic control mechanism is needed.

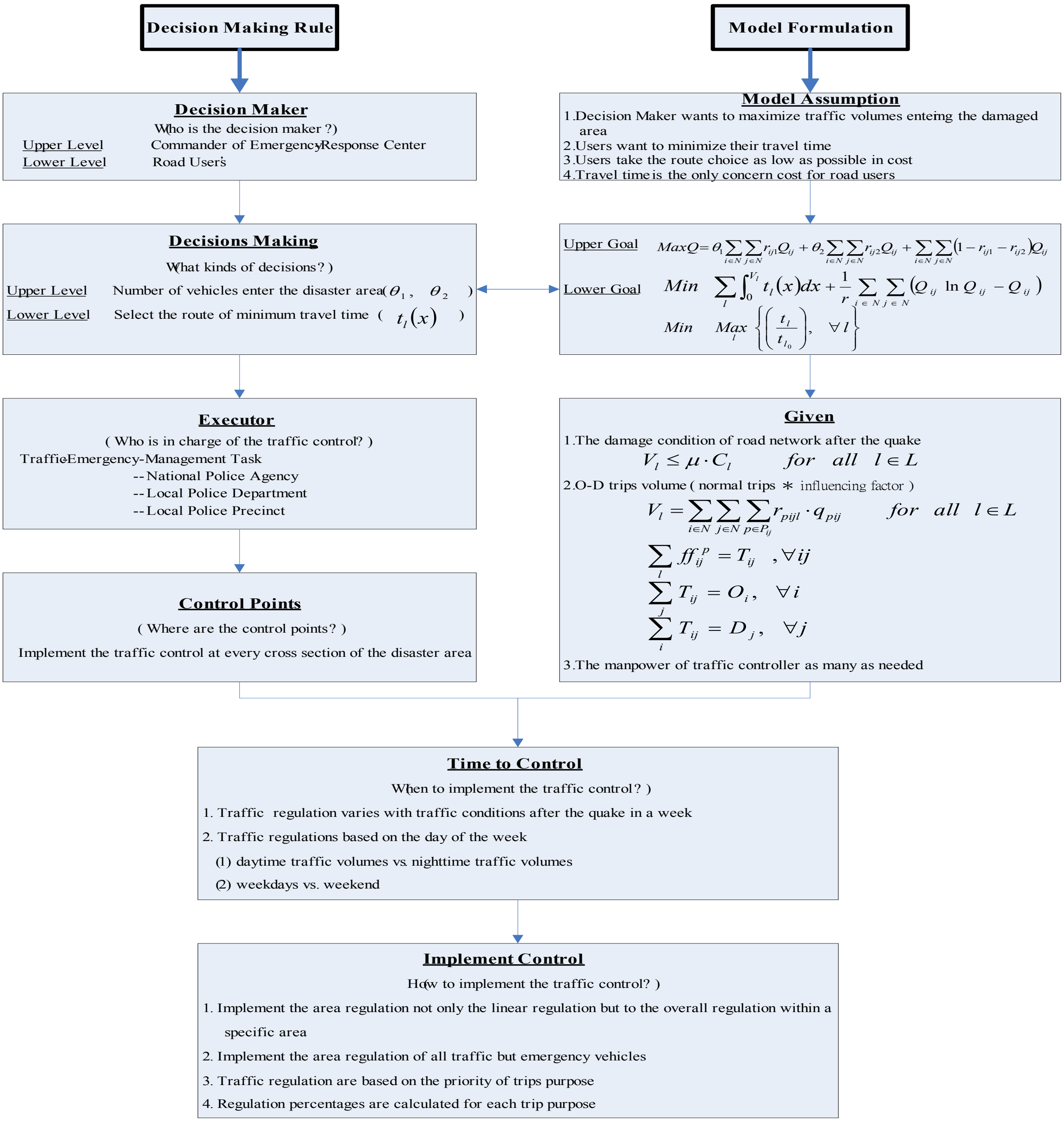

Figure 2 Traffic Control Decision-making Concept and Model Formulation

Since damage to urban road network system causes congestion in many parts of the network, efficient traffic management is urgently needed (Odani et al., 1996; Nakagawa et al., 1996). The real time traffic control is an interactive decision process. Bi-level optimization model is a practical and useful tool for solving decision problems in a hierarchical system. In solving the problem there are several questions needed to be answered, such as who is the decision maker, what kinds of decision will be made, who is in charge of traffic control, where the traffic control points are, when to implement traffic control and how to implement traffic control. All these question analyses and the basic concepts of bi-level programming model formulation are illustrated as figure 2.

3. MODEL FORMULATION AND CALIBRATION

Despite there is only little progress on predicting earthquakes, contingency study efforts can never be over-emphasized. This is particularly true in the case of Chi-Chi Earthquake. In the first couple days everything is in chaos. There is no enough experience to deal with such a kind of disasters. Decision makers can only rely on limited information and resources in hands. Therefore, rescue operation is not in a smooth process at the beginning. The study, after reviewing related literatures on earthquake operations, has explored various traffic-control measures in contingency and their effects. The study especially pays attention to how to make preparedness against unpredictable natural disasters, and tries to identify useful ideas for traffic control and rescue. An appropriate traffic control strategy in contingency is expected to improve the effectiveness and efficiency of rescue and restoration post disasters. The problem to be addressed is formulated as a multi-commodity, two-model (non-emergency and emergency vehicles) bi-level programming problem following the concept of network flow theory and interactive fuzzy approach.

3.1 Conceptual Model Formulation

While a disaster lasting, the blockage of roads and streets will be a problem for the missions of evacuation, restoration and rescue. It is necessary to balance travel demand and service supply in order to relieve traffic congestion. This paper proposes a multi-level optimization model to present the interactive decision process between roadway control decision-makers and road users. It is assumed that the decision is executed in a top-down hierarchy. The low-level decision-makers can make their choices under certain conditions determined by the high-level decision-makers. The problem definition discussed above is similar to the static two persons Stackelberg game and the interactive decision-making process (E. Stanley Lee, 2001). This type of decision process is well known and studied extensively under the title of bi-level programming problem.

The model assumes the commander of Emergency-Response Center of government in county and city levels located in earthquake-raided areas are the decision-makers. The objective of any decision is to meet the needs of emergency operation. The upper level objective in the model is to allow traffic to go through the disaster areas as much as possible under the condition of not exceeding the available roadway capacity. It can be treated as the minimum desired level of service.

The lower level objective is set to meet the emergency rescue needs while a combined road network assignment and trip distribution concept (CDA model suggested by Evens, 1976) is integrated. According to this arrangement the model can not only meet the requirements of the entropy model, but also can practically reflect users' travel behavior. It is assumed that road users will always choose the shortest route in respect of the travel time. Traffic control zones are designated by decision-makers by knowing the degrees of damages on roadways. The bi-level programming conceptual model is shown as below.

Upper Level Problem

$$MaxQ = \theta_1 \sum_{i\in N}\sum_{j\in N} r_{ij1}Q_{ij} + \theta_2 \sum_{i\in N}\sum_{j\in N} r_{ij2}Q_{ij} + \sum_{i\in N}\sum_{j\in N}\left(1 - r_{ij1} - r_{ij2}\right)Q_{ij} \quad (3.1)$$

Subject to

$$V_l \le \mu \cdot C_l \quad (3.2)$$

$$0 \le \theta_1, \theta_2 \le 1 \quad (3.3)$$

Lower Level Problem

$$Min \sum_l \int_0^{V_l} t_l(x)dx + \frac{1}{r}\sum_{i\in N}\sum_{j\in N}\left(Q_{ij}\ln Q_{ij} - Q_{ij}\right) \quad (3.4)$$

$$Min \ \ Max\left[\frac{\sum_l V_l \cdot t_l(V_l)}{\sum_l V_l \cdot t_l(0)}\right] \quad (3.5)$$

Subject to

$$\sum_{p\in P_{ij}} q_{pij} = \theta_1 r_{ij1}Q_{ij} + \theta_2 r_{ij2}Q_{ij} + \left(1 - r_{ij1} - r_{ij2}\right)Q_{ij} \quad for \ \ all \ \ i\in N, j\in N \quad (3.6)$$

$$V_l = \sum_{i\in N}\sum_{j\in N}\sum_{p\in P_{ij}} r_{pijl}\cdot q_{pij} \qquad for \ \ all \ \ l\in L \quad (3.7)$$

$$q_{pij} \ge 0 \quad for \ \ all \quad p\in P_{ij}, i\in N, j\in N \quad (3.8)$$

$$\sum_l ff_{ij}^{p} = T_{ij} \quad ,\forall ij \quad (3.9)$$

$$\sum_j T_{ij} = O_i, \ \ \forall i \quad (3.10)$$

$$\sum_i T_{ij} = D_j, \ \ \forall j \quad (3.11)$$

$$ff_{ij}^{p} \ge 0 \quad ,\forall l, i, j \quad (3.12)$$

Equation 3.1 represents the upper level objective which is trying to maximize the number of vehicles to enter the regulated areas. The objective function (Max Q) has three parts. The first part of the equation represents the maximum number of vehicles that can be allowed to enter the first encircled earthquake-raided zone under traffic control. The second part of the equation represents the maximum number of vehicles allowed to enter the second encircled earthquake-raided zone. The third part of the equation represents all traffic flows that are not subject to traffic controls within the two zones mentioned above. Parameters r_{ij1} and r_{ij2} are dummy variables presenting 0 or 1. For those vehicles traveling within the traffic control zones mark 1 otherwise mark 0. Adding the three parts together represents the entire traffic flows subject to traffic control. Equation 3.2 implies that total amounts of vehicles (emergency and non-emergency vehicles) entering the regulated disaster areas (including those already inside the areas) could not exceed the available roadway capacity. Equation 3.3 says that the value of traffic control ratio is ranging from 0 to 1.

Equation 3.4 represents the lower level objective which is to minimize the total travel time from users' perspective. The first item in this equation represents road network assignment. The second item of the equation defines trip distribution. Equation 3.5 is the second concern of the lower objective which is to meet the needs of emergency rescue. Equation 3.6 represents the traffic inflows on path p. The right hand side of Equation 3.6 composes three items representing traffic flows in the first zone, the second zone and the rest of areas subject to traffic control. Equation 3.7 represents the traffic flows on every road sections (V_l). It can be measured as the summation of all traffic flows passing link l on path p. Parameter r_{pijl} is another dummy variable, if vehicles passing link l on path p it will be marked as 1, otherwise as 0. Equation 3.8 is to assure the volume on p path (q_{pijl}) will always be positive.

Equation 3.9 represents the total amount of trips passing through path p. Equation 3.10 and Equation 3.11 represent the total amount of starting trips and ending trips, both are the outcome of trip distribution that should meet the principle of entropy model. Equation 3.12 is to guarantee the amounts of trip passing through path p will not be negative.

3.2 Variable Definitions

1. Decision Variables

Traffic control ratios（θ_i）in respect of different disaster periods, time frames and locations which can decide how many vehicles to enter the earthquake-raided areas.

2. Controllable Variables

N : a set of nodes

L: a set of links

P_{ij}: a set of paths for OD pair ij
C_l: capacity flow on link l
μ : the congestion level can be tolerated
γ : dispersion parameter
$t_l(0)$: free flow travel time on link l

3. Uncontrollable Variables

V_l: traffic flow on link l
Q_{ij}: traffic volume between OD pair ij
q_{pij}: p_{-th} path flow between OD pair ij
$t_l(x)$: travel time function on link l
$t_l(V_l)$: travel time on link l
O_i: number of trips from i
D_j: number of trips to j
ff^p_{ij}: number of trips on p_{-th} path
T_{ij}: number of OD pair ij
r_{ij1}: if OD pair ij is involved with 1st regulation, then 1, otherwise 0
r_{ij2}: if OD pair ij is involved with 2nd regulation, then 1, otherwise 0
r_{pijl}: if p_{-th} path between OD pair ij is included on link l then 1, otherwise 0

3.3 Model Calibration

Because most of the algorithms proposed for solving the simplest bi-level problems of the duo-ploy type are not computationally efficient for large hierarchy organizations. In fact, they are not very efficient even for bi-level problems. Recently, a completely different approach by exploring the typical fuzziness, vagueness, or the not-well-defined nature of a large hierarchical organization using fuzzy set theory was proposed by Lee and coworkers [Shih et al. 1996 and Shih and Lee 1999]. The resulting fuzzy interactive sequential approach has been proved to be a powerful one and can be used to help the decision-maker to solve practical problems encountered in large decentralized companies. In this paper, we use the proposed approach, which allows various different degrees of control are ideally suited for traffic management. And the advantages of this approach are two folds: Fist, the problem becomes much more simplified and thus it can be solved reasonably easily for fairly large practical problems and, secondly, the representation of the original problem is not only simplified but also much more realistic. In other words, since the real world problems for large organizations are generally fuzzy or not-well-defined, the existing classic algorithms are trying to solve a non-existing problem by assuming unrealistically accurate models and by ignoring the inherent fuzziness of large organizations.

3.3.1 A Fuzzy Bi-level Programming Algorithm

The problem is formulated following the rules of bi-level programming, with two decision-makers in two different hierarchical levels. The algorithm for this bi-level programming problem is defined as followings. The decision variables (x_1, x_2) are vectors representing the actions taken by the two decision-makers, where the upper-level one has control over vector x_1 and the lower-level one has control over vector x_2. Mathematically, the upper-level decision can be decided by solving the following problem.

$$Max \quad f_1(x_1, x_2) = c_{11}^T \cdot x_1 + c_{12}^T \cdot x_2 \tag{3.13}$$

Subject to:

$$(x_1, x_2) \in F_2 = \{(x_1, x_2) | A_1 x_1 + A_2 x_2 \leq b, \quad x_1, x_2 \geq 0\}$$

The solution can be presented as (x_1^U, x_2^U, f_1^U). On the other hand, the lower-level decision can be decided by solving the following problem.

$$Min \quad f_2(x_1, x_2) = c_{21}^T \cdot x_1 + c_{22}^T \cdot x_2 \tag{3.14}$$

Subject to:

$$(x_1, x_2) \in F_2 = \{(x_1, x_2) | A_1 x_1 + A_2 x_2 \leq b, \quad x_1, x_2 \geq 0\}$$

The solution can be presented as (x_1^L, x_2^L, f_2^L). If $(x_1^U, x_2^U) = (x_1^L, x_2^L)$, a optimal or preferred solution is reached. However, the two solutions are usually conflict because of the nature of the two objectives.

The upper-level DM understands that assuming the optimal decision x_1^U can also be the acceptable solution for the lower-level DM is obviously not practical. It is more reasonable to have some tolerance that gives the lower-level DM a room to search their optimal choice. The scope of the decision for vector x_1 can be described as "around x_1^U "with its maximum tolerance p_1. In other words, the most preferred decision is x_1^U and the worst acceptable decision is $(x_1^U - p_1)$ or $(x_1^U + p_1)$. The satisfaction or preference can be assumed as linearly increasing within the interval of $[x_1^U - p_1, x_1^U]$ and linearly decreasing within $[x_1^U, x_1^U + p_1]$. Decisions outside the interval $[x_1^U - p_1, x_1^U + p_1]$ are not acceptable. These assumptions can be formulated as the following membership function. The function follows the fuzzy set theory:

$$\mu_{x_1}(x_1) = \begin{cases} [x_1 - (x_1^U - p_1)] / p_1, & if \quad x_1^U - p_1 \leq x_1 \leq x_1^U \\ [(x_1^U + p_1) - x_1] / p_1, & if \quad x_1^U \leq x_1 \leq x_1^U + p_1 \\ 0, & otherwise \end{cases} \tag{3.15}$$

The upper-level DM must also reset his or her goal with some tolerance. The upper level may adopt a tolerance of $f_1^{'}$. Values of $f_1 > f_1^U$ is absolutely acceptable and values of $f_1 < f_1^{'}$ are absolutely unacceptable. The satisfaction or preference within the interval $\left[f_1^{'}, f_1^{U}\right]$ can be assumed as linearly increasing. The membership function can be formulated as follows:

$$\mu_{f_1}(f_1(x)) = \begin{cases} 1, & if \quad f_1(x) \geq f_1^U \\ \left[f_1(x) - f_1^{'}\right] / \left[f_1^U - f_1^{'}\right], & if \quad f_1^{'} \leq f_1(x) \leq f_1^U \\ 0, & if \quad f_1(x) \leq f_1^{'} \end{cases} \tag{3.16}$$

The lower level also reassesses his/her goal. Based on his/her tolerance or preference level, the lowest tolerable goal for the lower level is $f_2^{'}$. Thus, we have the following membership function for the goal of the lower level:

$$\mu_{f_2}(f_2(x)) = \begin{cases} 1, & if \quad f_2(x) \geq f_2^L \\ \left[f_2(x) - f_2^{'}\right] / \left[f_2^L - f_2^{'}\right], & if \quad f_2^{'} \leq f_2(x) \leq f_2^L \\ 0, & if \quad f_2(x) \leq f_2^{'} \end{cases} \tag{3.17}$$

The lower-level DM now can optimize his/her objective function under the new constraints of "x_1 is about x_1^U" and "f_1 is near or greater than f_1^U". The discussion above can be represented as the following membership functions.

$$\begin{aligned} &Max \quad f_2(x_1, x_2) = c_{21}^T \cdot x_1 + c_{22}^T \cdot x_2 \\ &subject \quad to: \\ &\qquad A_1 x_1 + A_2 x_2 \leq b \\ &\qquad \mu_{f_1}(f_1(x)) \geq \alpha \\ &\qquad \mu_{x_1}(x_1) \geq \beta \\ &\qquad \alpha \in [0, \ 1] \\ &\qquad \beta \in [0, \ 1] \\ &\qquad x_1, x_2 \geq 0 \end{aligned}$$

Where scalars α and β are the minimum acceptable degrees of satisfaction for the objective $f_1(x)$ and the decision variable x_1, respectively. Their feasible ranges are constrained by $\mu_{f1}(f_1(x))$ and $\mu_{x1}(x_1)$. The lower-level DM can compare various solutions corresponding to the upper-level DM's satisfactory levels α and β. The membership function represented by γ, δ with $0 \leq \gamma, \delta \leq 1$ can be considered as the degree of satisfaction. To satisfy both upper and the lower level's degrees of satisfaction, the solution must be the minimum of $\alpha, \ \beta \ \ \gamma$ and δ, this conclusion can be represented as $\lambda = Min\{\alpha, \ \beta, \ \gamma, \ \delta\}$. Where λ is a fuzzy number resulting from the intersection of the three membership functions. Following the traditional fuzzy approach λ must be maximized in order to obtain the maximum degree of satisfaction. Therefore, the following multi-objective programming problem needs to be solved.

$$
\begin{aligned}
&Max \quad \lambda = Max\left(\min\{\alpha, \beta, \gamma, \delta\}\right) \\
&subject \quad to: \\
&\qquad \mathbf{A}_1\mathbf{x}_1 + \mathbf{A}_2\mathbf{x}_2 \le \mathbf{b} \\
&\qquad \boldsymbol{\mu}_{x_1}(\mathbf{x}_1) \ge \alpha \cdot \mathbf{1} \\
&\qquad \mu_{f_1}(f_1(\mathbf{x})) \ge \beta \\
&\qquad \mu_{f_2}(f_2(\mathbf{x})) \ge \gamma \\
&\qquad \mu_{f_3}(f_3(\mathbf{x})) \ge \delta \\
&\qquad \mathbf{x}_1 \ge \mathbf{0} \\
&\qquad \mathbf{x}_2 \ge \mathbf{0} \\
&\qquad \alpha \in [\mathbf{0,1}] \\
&\qquad \beta, \delta \in [0,1]
\end{aligned} \tag{3.18}
$$

3.3.2 Applying Fuzzy Approach to Solve the Model

$$
\begin{aligned}
&Max \quad \lambda = Max\left(Min\{\alpha, \beta, \gamma, \delta\}\right) \\
&Subject \quad to: \\
&\qquad f_1(\theta_i) = \theta_1 r_{ij1} Q_{ij} + \theta_2 r_{ij2} Q_{ij} + (1 - r_{ij1} - r_{ij2}) Q_{ij} \\
&\qquad f_2(V_l) = \sum_l \int_0^{V_l} t_l(x)dx + \frac{1}{\gamma}\sum_{i\in N}\sum_{j\in N}\left(T_{ij}\ln T_{ij} - T_{ij}\right) \\
&\qquad f_3(V_l) = \sum_l V_l \cdot t_l(V_l) \Big/ \sum_l V_l \cdot t_l(0) \\
&\qquad \sum_{k\in K_{ij}} q_{kij} = \theta_1 r_{ij1} Q_{ij} + \theta_2 r_{ij2} Q_{ij} + (1 - r_{ij1} - r_{ij2}) Q_{ij} \\
&\qquad V_l = \sum_{i\in N}\sum_{j\in N}\sum_{k\in K_{ij}} r_{kijl} \cdot q_{kij} \\
&\qquad \sum_p ff_{ij}^{\,p} = T_{ij} \qquad \forall_{ij} \\
&\qquad \sum_j T_{ij} = O_i \qquad \forall_i \\
&\qquad \sum_i T_{ij} = D_j \qquad \forall_j \\
&\qquad \mu_{\theta_i}(\theta_i) \ge \alpha \cdot \mathbf{1} \\
&\qquad \mu_{f_1}[f_1(\theta_i)] \ge \beta \\
&\qquad \mu_{f_2}[f_2(V_l)] \ge \gamma \\
&\qquad \mu_{f_3}[f_3(V_l)] \ge \delta \\
&\qquad V_l \ge 0 \quad for \quad all \quad l \in L \\
&\qquad q_{kij} \ge 0 \quad for \quad all \quad k \in K_{ij} \quad i \in N, \quad j \in N \\
&\qquad ff_{ij}^{\,p} \ge 0 \qquad \forall_{l,i,j} \\
&\qquad \theta_i \in [0,1] \qquad i = 1, \ 2 \\
&\qquad \alpha \in [\mathbf{0,1}] \\
&\qquad \gamma, \beta, \delta \in [0,1]
\end{aligned} \tag{3.19}
$$

4. NUMERRICAL EXAMPLES

4.1 A Hypothetical Network

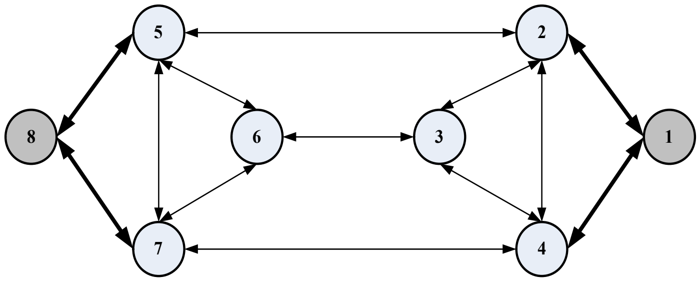

Figure 4 Test Road Network

Table 4-1 Parameter for a fuzzy Traffic Control Problem (with 8 nodes and 26 arcs)

Link no.	From / To	Fuzzy Link Capacity(normal)	Fuzzy Link Volume(normal)	Fuzzy Travel Time(normal)	Traffic demand
01	1 → 2	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
02	1 → 4	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
03	2 → 1	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
04	2 → 3	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
05	2 → 4	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
06	2 → 5	(280, 300, 320)	(200, 220, 240)	(5.21, 5.22, 5.23)	(260, 280, 300)
07	3 → 2	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
08	3 → 4	(90, 100, 110)	(70, 80, 90)	(3.16, 3.18, 3.20)	(90, 100, 110)
09	3 → 6	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
10	4 → 1	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
11	4 → 2	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
12	4 → 3	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
13	4 → 7	(280, 300, 320)	(200, 220, 240)	(5.20, 5.22, 5.24)	(260, 280, 300)
14	5 → 2	(280, 300, 320)	(200, 220, 240)	(5.20, 5.22, 5.24)	(260, 280, 300)
15	5 → 6	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
16	5 → 7	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
17	5 → 8	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
18	6 → 3	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
19	6 → 5	(90, 100, 110)	(70, 80, 90)	(2.11, 2.12, 2.13)	(90, 100, 110)
20	6 → 7	(180, 200, 220)	(130, 150, 170)	(2.08, 2.09, 2.10)	(160, 180, 200)
21	7 → 4	(280, 300, 320)	(200, 220, 240)	(5.20, 5.22, 5.24)	(260, 280, 300)
22	7 → 5	(180, 200, 220)	(130, 150, 170)	(3.12, 3.14, 3.16)	(160, 180, 200)
23	7 → 6	(180, 200, 220)	(130, 150, 170)	(2.08, 2.09, 2.10)	(160, 180, 200)
24	7 → 8	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
25	8 → 5	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)
26	8 → 7	(370, 400, 430)	(180, 200, 220)	(4.03, 4.03, 4.04)	(570, 600, 630)

We assumed a fuzzy bi-level traffic control road network with 8 nodes and 26arcs. There are 4 centroids of which centroid 6, 3 are inside the disaster area and centroid 1, 8 are outside the disaster area. The fuzzy data are summarized in Table 4-1 and the structure of the network is shown in Figure 4. Each link is assumed to have two costs: one is corresponding to its normal state and the other is in degraded state. The OD traffic volume under normal conditions is listed in Table 4-1. Then, calculation of the road network capacity under each OD traffic volume in Table 4-1 is 6600 trips. Calculation of the road network capacity excluding the external-external trips on a degraded road network gives 4940 trips, where the traffic capacity has been decreased by 60% (link 04, 05, 07, 08, 09, 11, 12, 18 of road network), 70% (link 15, 16, 19, 20, 22, 23 of road network) and the other 80% compared with the normal road network. As a result, the degraded road network capacity is less than 75% as normal network capacity.

4.2 Test Results and Discussion

The upper and lower level's decision makers solve their problems independently by solving Equations 3.1, 3.4 and 3.5 separately subject to its constraints. If these two solutions coincide, the optimal or preferred solution of the system is obtained. Otherwise, the upper-level decision maker decides her tolerances on the goal and the decisions in terms of membership functions. Meanwhile, the lower-level decision maker also decides his tolerance on the goal in terms of membership functions. In order to satisfy both decision-makers, the interactive approaches are used to obtain satisfactory membership functions. Since true optimum cannot be defined easily due to the interactions, there is no reason to assume the optimum is at the corner point. Thus, we consider a compromise solution, which is acceptable to all the decision-makers. The proposed approach is very efficient and does not increase the complexity or the size of the original problem. Since the set of our constraints in the model may not be a convex set, the uniqueness of the model may not be guaranteed. Moreover, since our purpose is to find a satisfactory compromise solution, even if the current solution obtained is a local optimal solution, we still could accept it.

The above problem can be solved by LINGO mixed-integer software. The proposed approach first solves upper and lower-level decision objects separately subject to its constraints. The optimal solutions for the upper and lower-level decision problems are $\left(x_1^U, x_2^U\right)$= (0.23, 0.29) with f_1^U=6600 and $\left(x_1^L, x_2^L\right)$= (0.20, 0.015) with f_{21}^L=6110 and $\left(x_1^L, x_2^L\right)$= (0.20, 0.015) with f_{22}^L=1.04. Using these solutions as reference, and set f_1^U = 6600 and assume $f_1^{'}$=2470, $f_{21}^{'}$=2470 and $f_{22}^{'}$=1.0. Let the upper-level DM's decision variable x_1 be around with the negative and positive side tolerances equal to 0.15 and 0.31, respectively. Using Equations 3.15, 3.16 and 3.17, the membership functions $\mu_{x1}(\bullet)$, $\mu_{f1}(\bullet)$, $\mu_{f21}(\bullet)$ and $\mu_{f22}(\bullet)$ are obtained. The compromise solution of which is $f^* = \left(f_1^*, f_{21}^*, f_{22}^*\right)$= (2420, 2240, 2.53) with $x^* = \left(\theta_1^*, \theta_2^*\right)$ = (0.21, 0.02). The overall satisfaction of the present solution is $\lambda = 0.45$.

The result indicates that the first stage regulation rate $(1-\theta_1^*)$ is 0.79, and the second stage regulation rate $(1-\theta_2^*)$ is 0.98. The value of the ratio for the first stage regulation implies that it can accept about one fifth of the traffic from outside the regulated area. In contrast, the regulation rate of the second stage indicates that it is almost prohibited into the regulated area completely. That is to say, there remains a certain amount of road network capacity. It is better to give the first priority to emergency rescue vehicles from outside the regulated area, and non-emergency car should be regulated.

In order to deal with the reduction of road network capacity in disaster areas, it is necessary for decision makers to establish a systematic approach and maintain the physical infrastructures to implement traffic management before and after a major earthquake. It is evident that traffic facilities should be built with the most up-to-date specification for seismic resistance and would be develop the countermeasures of contingency plans before earthquake. It should be emphasized that the effective traffic management is dependent on reliable traffic data not only during the normal operation but also after the major earthquake. Through the use of high-quality data, the reliability of traffic regulation throughout the road network will be enhanced.

5. CONCLUSIONS AND RECOMMENDATIONS

By developing a bi-level programming model, this study tries to build a mechanism which could provide traffic control strategy for recovery from chaos post earthquake as soon as possible. More specifically, the strategy helps decision-makers to make appropriate traffic control decisions considering different perspectives of objective and traffic situations. To prove the feasibility of the models, a sample data collected from Chi-Chi Earthquake is used to verify the model. To solve the model efficiently, the fuzzy set concept has been applied in the process of model calibration.

Analytical results show that the bi-level programming model and interactive fuzzy approach are flexible and effective in solving the problem of traffic control decision-making under difficult conditions like disasters. However, there still are some limitations and recommendations found in this study worth to be addressed in future studies.

First, since the lower level objectives in the bi-level programming model are analyzed following the “User Equilibrium”. If the problem covers an extensive time period, the problem complexity will increase significantly and then the computation efficiency will be a serious concern for the model’s application. It is suggested that to consider adopting the “System Equilibrium” instead of the “User Equilibrium”. Secondly, obtaining comprehensive data to reflect the true damages in the earthquake-raided areas to verify the feasibility of the models is still a difficult task at this stage. It should be done in the near future, although the data recovery and preservation like the incident itself has a lot of confusion. Thirdly, incorporating temporal dimension into the model such that the dynamics of flow variations over time can be better represented.

Finally, the study suggests that developing an efficient information and decision support system will be more worthwhile than establishing comprehensive contingency plans for some unexpected disasters. Particularly, it is believed that the development of ITS technology can be of more helps in improving existing traffic management systems. In that case, some limitations of the proposed model in application might not be a problem in the future.

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